WEDNESDAY, MAY 9

8:30am – 9:30am  Automotive Aluminum Wire….in Your Future?

Don Price, Ph.D., Liaison from Ford Motor Co. to EWCAE of USCAR, LLC
Rakesh Patel, Chairman of ISO Automotive Electrical Cables Committee
Kurt Seifert, Delphi Packard Electrical/Electronic Architecture
IS ALUMINUM WIRE IN YOUR FUTURE?

WHAT ARE THE DRIVERS?

Coming Soon?  Coming Never?
MARKET DRIVERS FOR ALUMINUM... COST AND VOLATILITY

Volatile Copper Prices!

![Graph showing volatile copper prices from Jan-03 to Jan-12](image)
MARKET DRIVERS ... COMMITMENT TO WEIGHT REDUCTION

Aggressive CAFE Standards!

The fleet-wide average will be 54.5 MPG.

Consumers will have saved $1.7 TRILLION at the pump over the life of the program.

A family that purchases a new vehicle in 2025 will save $8,200 in fuel costs when compared with a similar vehicle in 2010.

Over the life of the program, the standards will:
- Save 12 billion barrels of oil.
- Eliminate 6 billion metric tons of carbon dioxide pollution.

This program, together with standards already put into place by this administration for Model Years 2011-2016, will result in significant cost savings for consumers at the pump, dramatically reduce oil consumption, cut pollution and create jobs.
ALUMINUM CABLE MEETS MARKET DRIVERS

- Offers LOWER COST per Amp
- Reduces exposure to volatile copper market
- Provides up to 48% mass reduction over copper
- Eases assembly - Lighter, easier vehicle assembly
- Improves fuel economy

BUT…

- ALUMINUM IS “DIFFERENT” THAN COPPER
- IMPLEMENTATION HAS CHALLENGES
ALUMINUM CABLE A “HISTORY LESSON”

During the mid 60’s and into the mid 70’s copper was at an all time high price level, which made it cost prohibitive for use in residential wiring.

Underwriters Laboratories had approved aluminum for interior wiring purposes as early as 1945, providing it was installed properly.

⚠️ Use at least one wire gauge larger than copper for each current rating
⚠️ Use only approved switches, outlets, and fixtures
⚠️ Use an oxide inhibitor as directed

Faulty installation, incompatible materials, and lack of maintenance led to the notorious aluminum wiring fires.

❌ Almost all reported problems involved 10 AWG and 12 AWG branch circuit connections where installers did not follow the guidelines.

CONCLUSION: Aluminum termination is different from copper termination. Special precautions / technologies are required, especially in harsh vehicle environments.
BUT IT CAN WORK IN VEHICLES

TIMELINE OF ACTUAL APPLICATIONS

1969 to 1985: Delphi produces copper clad aluminum battery cable ~35 million meters (USA)

1974 to 1989: Delphi produces solid core aluminum primary cable ~900 million meters (USA)

19xx to Present: Aluminum battery cable with various welding/bonding termination technologies becomes cost competitive (Europe and USA)

2010: Toyota introduces stranded AL primary cable implemented in door harnesses (Japan)

2011: Delphi implements sonic welded aluminum battery cable (USA)

2000: BMW Introduces friction weld Al battery cable for rear battery applications. (Germany)

2000: G&G Introduces plasma weld Al battery cable for rear battery applications. (Germany)
HOW IS ALUMINUM CABLE DIFFERENT THAN COPPER?

Six important ways Al is more challenging than Cu.

1. Lower conductivity
2. Reduced break strength / flex
3. Oxides form an insulating layer
4. Differences in thermal expansion
5. Galvanic corrosion occurs
6. Stress relaxation and creep can loosen terminations
HOW IS ALUMINUM CABLE DIFFERENT THAN COPPER?

1. Aluminum has only about 60 percent of the conductivity of copper

MUST UPSIZE CONDUCTOR

<table>
<thead>
<tr>
<th></th>
<th>Aluminum</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Wire Gage Size</td>
<td>18ga</td>
<td>20ga</td>
</tr>
<tr>
<td>Equivalent Mass</td>
<td>52%</td>
<td>100%</td>
</tr>
<tr>
<td>48% Mass Savings</td>
<td></td>
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</table>
HOW IS ALUMINUM CABLE DIFFERENT THAN COPPER?

2. Due to reduced break strength and elongation, aluminum is not optimal solution for vehicle applications <0.75mm²

**CURRENT USE LIMITED TO 18GA and LARGER**
HOW IS ALUMINUM CABLE DIFFERENT THAN COPPER?

3. When exposed to air, aluminum oxides form an insulating layer on wire surface (including inter-strand resistance)

TERMINATION MUST FRACTURE OXIDES TO PROVIDE METAL-TO-METAL CONTACT
HOW IS ALUMINUM CABLE DIFFERENT THAN COPPER?

4. Differences in thermal expansion
   - Ratio of Al : Cu = 1.4 : 1
   - Thermal cycling of a termination can create possible voids and plastic deformation leading to loose connections and higher contact resistance

=> DESIGN TERMINATIONS TO WITHSTAND THERMAL CYCLING/SHOCK
HOW IS ALUMINUM CABLE DIFFERENT THAN COPPER?

5. Galvanic corrosion occurs when two different metals electrically contact each other and an electrolyte is present.

MAY NEED TO SEAL TERMINATIONS TO INHIBIT CORROSION

Over 0.15V difference is not recommended for exposure to electrolytes, humid or wet areas. Aluminum is susceptible to corrosion.
6. Aluminum stress relaxation and creep can loosen terminations over time

DESIGN ROBUST ALUMINUM CONDUCTORS AND TERMINATION SYSTEMS
DIVIDE AND CONQUER
3 RANGES OF DELPHI ALUMINUM CABLE PRODUCT OFFERINGS

<table>
<thead>
<tr>
<th>Cable</th>
<th>Sizes</th>
<th>Core Construction</th>
<th>Termination Technology</th>
<th>Corrosion Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Gauge</td>
<td>0.75 to 2.5mm²</td>
<td>Annealed high strength, high conductivity alloy</td>
<td>Engineered CRIMP-ONLY technology with new terminal core crimp designs</td>
<td>Sealant applied to crimp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19-strand construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate Gauge</td>
<td>3 to 8mm²</td>
<td>Annealed 99.5% pure aluminum alloy</td>
<td>New WELD + CRIMP technology with new terminal core crimp designs</td>
<td>Sealant applied to crimp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increased number of strands for flexibility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power / Battery Gauge</td>
<td>10 to 160mm²</td>
<td>Annealed 99.5% pure aluminum alloy</td>
<td>SONIC WELDING technology used to connect all strands to terminal</td>
<td>Dual-wall heat-shrink (with sealant)</td>
</tr>
</tbody>
</table>
ARE WE COMING TO A “TIPPING POINT?”

… A “Tipping point” of being favorable to Aluminum?

Benefits

CHALLENGES

Where is the balance point?
ARE WE COMING TO A “TIPPING POINT?”

-- We help by changing the implementation costs?

Team of USCAR Will Develop the Standard Processes
STANDARD PROCESS BY EWCAP?

YES! USCAR Teams focus on standards to:

- Accelerate technical development
- Increase value of research investment
- Improve quality / reduce cost
- Provide common methods to foster growth

- The EWCAP “Standard aluminum termination process initiative”

Started April 24...... ..........................will end Oct 1, 2012
STANDARD EQUIPMENT EXAMPLE

Possible applicator of sealing material)

Possible “crimp” applicators: Ult. weld, 2-step, spring loaded

Possible common cutter technology

Possible common equipment (keep current cutter / applicator)
Harness makers will not accept AL if terminal makers have different strategies.
Al battery cables in production starting in 2000 in Europe…
… used a different convention:

• Conversion from Cu to Al sizes was based on conductivity
• This created non-ISO sizes for Al cables
• A non-ISO (LV112-2) German OEM standard) for Al cables was released
• Without ISO intervention, we’d have an unfriendly collection of different wire dimensions for different regions
ISO 6722-2 Al cable standard is in the final stage of approval

1. Al size conversion is based on cross sectional (CSA) area (ISO sizes) to minimize the termination system impact

2. Conductivity of Al cable reduced to approx. 60% of the same size Cu cable

3. Al cable resistance requirements are based on CSA

4. Al cable sizes: 0.75 mm$^2$ – 120 mm$^2$, including primary wire and battery cable sizes
# Copper Vs. Aluminum (ISO metric) wire sizes

<table>
<thead>
<tr>
<th>Cu size mm²</th>
<th>Plain Copper Max Resistance mΩ/m</th>
<th>Al size mm²</th>
<th>Max Resistance mΩ/m (Al)</th>
<th>Max Resistance mΩ/m (Al alloy)</th>
</tr>
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<tbody>
<tr>
<td>0.5</td>
<td>37.1</td>
<td>0.75</td>
<td>41.2</td>
<td>43.6</td>
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<tr>
<td></td>
<td></td>
<td>1</td>
<td>30.8</td>
<td>32.7</td>
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<tr>
<td>0.75</td>
<td>24.7</td>
<td>1.25</td>
<td>24.8</td>
<td>26.3</td>
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<tr>
<td>1</td>
<td>18.5</td>
<td>1.5</td>
<td>21.2</td>
<td>22.4</td>
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<tr>
<td></td>
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<td>2</td>
<td>15.7</td>
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<tr>
<td>1.5</td>
<td>12.7</td>
<td>2.5</td>
<td>12.7</td>
<td>13.4</td>
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<tr>
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<td>9.42</td>
<td>3</td>
<td>10.2</td>
<td>10.9</td>
</tr>
<tr>
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<td>7.6</td>
<td>4</td>
<td>7.85</td>
<td>8.32</td>
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<tr>
<td>2.5</td>
<td>6.15</td>
<td>5</td>
<td>6.57</td>
<td>6.96</td>
</tr>
<tr>
<td>3</td>
<td>4.71</td>
<td>6</td>
<td>5.23</td>
<td>5.55</td>
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<tr>
<td>4</td>
<td>3.94</td>
<td>8</td>
<td>3.97</td>
<td>4.2</td>
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<tr>
<td>5</td>
<td>3.14</td>
<td>10</td>
<td>3.03</td>
<td>3.21</td>
</tr>
</tbody>
</table>
Is Automotive Aluminum Wire in Your Future?  
Yes... We cannot predict the date.

USCAR/EWCAP contact information:  
EWCAP@USCAR.org

Questions?